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The Costs of Food Safety: a Methodological Review

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The Costs of Food Safety – a Methodological Review

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Abstract

This working paper through a survey of the scientific literature reviews the role of economics in food safety risk management and the current methodological state of the art concerning the evaluation of costs regarding microbiological food safety in a supply chain perspective. Cost analysis related to microbiological food safety is an example of a multidisciplinary field of research, where insights from natural sciences are combined with methods from economics and other social sciences. Measurement of the effects of food safety interventions are often based on methods and data from natural sciences, whereas the measurement of costs is based on economic methods. In this working paper much of the literature surveyed on cost analysis basically represents three methodological approaches: accounting economic-engineering as well as econometrics approaches – each with their own strengths and weaknesses.

The choice of analytical approach depends on the analytical purpose and the scope of analysis, e.g. process, firm, sector, chain, national or international levels. Hence the potential inclusion of further effects, e.g. societal benefits generated from reduced illness or macroeconomic consequences of restrictions on international trade. Although a considerable list of literature on the economic perspectives to microbiological food safety exists, as this working paper demonstrates, there still remain a number of substantial issues, where further research is needed to improve the possibilities for suitable analysis of the economic consequences of various intervention strategies to enhance the level of food safety.

Keywords

Costs, cost-effectiveness, economic methodologies, microbiological food safety

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Preface

Three research projects efficacy, cost benefit and consumer perception of post harvest pathogen reduction of fresh pork (DECONT), Risk perception and cost benefit analysis of interventions to control *Campylobacter* (CAMPY) and Balancing microbiological safety against other food quality parameters (QUALYSAFE) are carried out during the period 2005-2009. All the projects are financed by the Directorate for Food, Fisheries and Agri-Business under the Danish Ministry of Food, Agriculture and Fisheries.

Within the area of economics, one of the aims of the three projects is to review the literature of the costs of food safety, which is reported in the working paper. In the literature review special emphasis has been put on the description and evaluation of alternative analytical approaches to perform cost analyses of microbiological hazards in the production and consumption of food products.

Assistant professor Lartey G. Lawson, senior research fellow Jørgen Dejgaard Jensen, and research director Mogens Lund have written the working paper.

The working paper has been reviewed by senior advisor Henning Otte Hansen.

Mogens Lund
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Production and Technology Division, December 2007

1. Introduction

1.1. The role of economics in food safety control

A rather large amount of literature has been published on the economics of food safety. The overall aim of economic analysis is to provide decision support and policy guidance on how best to achieve the goal of a safer food supply and consumption. Although market competition and public regulations governing the production, transportation and distribution of food products may create benefits by increasing the safety levels of the food supply and reducing the risk of illness, these mechanisms can also increase producers' costs and eventually raise food prices. Thus, the economic challenge at hand is to ensure that the implemented actions and regulations maximize the net benefits of increasing food safety. Analytically, this is accomplished by equating the marginal benefits of safer food with the marginal costs of achieving food safety goals.

Many different policy approaches can be taken to improve the safety of the food supply and consumption. Among these are:

- Improving the meat inspection system;
- Educating consumers, retailers, and food service workers, and promoting safe food handling;
- Pasteurization/decontamination/irradiation of meat and poultry products; and
- Using information approaches to food safety: labelling, branding and providing other food-safety information about products or production methods.

All these opportunities have the potential to improve the safety of food products. The role of economics is to identify the costs and benefits of intervention strategies within each potential policy, rank policies on the basis of their benefits and costs, and identify the distributional consequences of such policies for farmers, food processors, retailers and consumers (Crutchfield et al., 1997).

However, in reality many complex issues are embedded in the economic analysis of food safety. Among these are information and incentive problems. All food products contain some level of food hazards, some of which may be pathogens such as bacteria, virus, or fungi, which may cause illness in humans. In many cases there are no easy ways for consumers to determine if there is a health risk from these or other hazards (such as pesticide residues); and as e.g. pathogens are not visible by the eye, firms may also be reluctant to voluntarily incur extra costs to improve the food safety of

their products. Furthermore, the unobservable nature of many food hazards may give rise to externalities if producers or consumers actions incur costs to others in their handling of food items.

Information asymmetries and uncertainties may give rise to market failures. Consumers do not have complete information about the safety of the products they buy, and producers do not always have any economic incentive to provide this information. If consumers cannot distinguish different safety levels in food products, firms may not wish to incur the extra cost of providing more than the minimum required level of safety in the products they market. In cases where firms provide food-safety information through e.g. product labels, there is a potential risk that some firms are making unrealistic health-risk claims in labelling or advertising.

Consequently, a non-regulated market may yield greater-than-optimal levels of food hazards in the food supply and thus excessive human health risk, which could result in higher levels of illness and mortality from these hazards. However, regulators do not possess perfect information about food chain actors' possibilities and incentives for adjusting to policy interventions. Such information and incentive problems have to be addressed if public welfare is to be increased by reducing the level of food hazards in food production and consumption, by increasing consumers' knowledge in order to reduce their risk of exposure to food-borne illness, and by assisting public regulators in the identification and ranking of policies for improved food safety to the society.

In the understanding of various food supply chain participants regarding their actions, provision of information, etc., economic analyses play a key role. In order to understand, which knowledge can be derived from economic analysis – and how this knowledge can be derived - there is a need for an overview of the available analytical approaches, including the respective strengths and weaknesses of these approaches.

1.2. Objectives

The objective of this report is to provide a literature review of cost studies of food safety and thus summarize and discuss the state of the art on the subject.

The focus of the review is on methodological issues such as which cost categories are considered in the food safety literature and how these costs are evaluated? Often, it is most easy to identify the direct costs of new food safety interventions, e.g. direct investments in new equipment and variable costs incurred for additional water and extra

labour. However, the implementation of new interventions in food companies may also lead to some indirect costs such as adjustment costs if the company is becoming less competitive or even is driven out of the market. These indirect costs are generally more difficult to measure than the direct costs associated with improvements in food safety, but they may also be more important from an economic welfare perspective.

Among food safety hazards, human health risks are highest from foodborne pathogens such as *Campylobacter* and *Salmonella* (Buzby, 2003). Therefore, the emphasis in the survey is on microbial hazards although important lessons can be learnt from the literature on especially the costs of pesticide regulation and animal health economics, respectively.

1.3. Outline of the report

The review starts in chapter 2 with a review of methodology and data issues involved in the costs of food safety. Risk analysis has become the foundation for estimating the costs and benefits of food safety improvements. It has also been included in the HACCP system, which is becoming the most common approach to food safety control in the food industry worldwide. As discussed in chapter 2, a large share of the literature on food safety costs could be considered as one of three main approaches: the accounting, the economic-engineering and the econometric approach. Each of these have their own pros and cons and should therefore be applied according to the available data and economic issues investigated. It is argued that lack of data constitutes one of the major obstacles to provide reliable cost estimates for various stages of food safety analysis.

Costs and cost effectiveness issues and studies are reviewed in chapter 3. As a first step, the characteristics of cost-effectiveness analysis are revealed and discussed. Cost effectiveness analysis refers simply to the evaluation of costs relative to some effect measures that are not monetized. A theoretical framework for cost analysis is presented in the second part of the chapter. The aim of this framework is to provide an economic understanding of the implications of using the accounting and alternative approaches to cost analysis of food safety technologies. In the third and last part of the chapter a large number of cost and cost effectiveness studies are reviewed according to a number of criteria. These include the applied methodology, categories of costs and stages of the food chain considered. Additionally, relevant comments on results and conclusions are provided.

Where the balance between private benefits and costs matters in a company perspective, the question from a society point of view is whether the benefits from a given improvement exceed the costs and how this improvement is ranked relative to other possible improvements that could be made with the same resources from a broad society perspective. Chapter 4 deals with different approaches to valuation of benefits related to food safety, as well as the use of these methods in applied cost-benefit analysis. Compared to a cost effectiveness analysis, cost benefit analysis poses two additional challenges: valuation of non-monetary benefits and costs, and discounting. A policy perspective is adopted in the chapter. Reliable estimates of the benefits and costs are required to guide the selection between alternative measures to improve food safety.

The final chapter concludes and discusses some of the main findings from the review and draws some perspectives for future regulation and research priorities. The strengths and weaknesses of the accounting, economic-engineering and econometric approaches are evaluated and it is concluded that the appropriate choice of analytical tool for cost evaluation of food safety depends on the scope of the analysis. The summary is followed by a discussion of the needs for future research into the costs of food safety. As one research need, it is pointed out that rather few studies have been found, which address the issue of cost-effective design of intervention strategies, e.g. what would be the cost-effective level and mix of interventions etc? Furthermore, it is argued that there is a need of research studies addressing the costs and cost effectiveness of food safety interventions in a holistic supply chain perspective.

2. General methodology and data issues

The scientific foundation for the control of food safety is risk analysis, which has a threefold role (NRC, 1998). It provides a basis for identifying where resources should be allocated in the short term; it constitutes a mechanism for determining where public and private efforts should be directed in the long run, especially with respect to research and preventive measures; and it yields important information for estimating and analysing the costs and benefits of policy alternatives. However, the question is how risk analysis can be integrated into cost analysis of food safety: One important question is how to choose the method for cost estimations? Another question is how to collect the necessary data to perform the cost analysis? This chapter provides a discussion on overall methodological and data issues related to the costs of food safety control.

2.1. Principles of food safety control

Many governments have adopted an approach to ensure the safety of the food supply, based on a “scientific foundation” for food-safety control. The foundation is based on risk analysis, which is a three-stage process described in Henson and Caswell (1999):

1. risk assessment: an assessment is made of the risk to human health associated with a particular food-borne hazard
2. risk management: decisions are made regarding the acceptable level of risk and measures implemented for the control of this risk, and
3. risk communication: information about the risk and chosen methods of control are communicated amongst interested parties.

Within this framework it is generally agreed to separate risk assessment and risk management.

The general acceptance of risk analysis as the basic principle has led regulators and international agencies to adopt the HACCP (Hazard Analysis and Critical Control Points) system as the main regulatory tool for the control of food safety. Risk analysis also constitutes the foundation for food safety policies in the European Union (EU). Thus, the union’s food policy is based on the three above elements of risk analysis. EU’s White Paper on Food Safety (White paper on food safety 2000) identifies the guiding principles for food-safety policy to include (Jensen, 2003):

- taking a comprehensive, integrated approach throughout the food chain

- identifying responsibility for food safety through the food chain – from farm to table
- basing food-safety policy on the foundation of risk analysis in the design of standards; and
- preventing hazards through the use of the HACCP system

The HACCP system was mandated by European Union in directive 93/43, which became implemented in December 1995. It required member states to adopt a HACCP approach in their food safety legislation that forced food companies to follow HACCP principles in their production processes. The guiding principle is that the food industry should be responsible for monitoring the food safety, whereas the overall responsibility should be placed within national and international authorities. In the United States, HACCP was mandated for seafood in 1994, for meat and poultry in 1996, for shell egg handling in 2000 and for fresh fruit juice in 2001.

As noted by Loader and Hobbs (1999), the implementation of HACCP reflects a change in control philosophy, representing a move away from an end-product food safety inspection approach to a preventive focus, with the responsibilities for risk management placed mainly on the food companies themselves. The aim of the HACCP system is to establish process control by identifying the points in the production process that are most critical to monitor and control. The system can be adopted to control any stage of food production in the food system. Seven basic principles are involved in developing and operating a HACCP program:

1. Assess the hazard, list the steps in the process where significant hazards can occur, and describe the prevention measures
2. Determine critical control points (CCPs) in the process
3. Establish critical limits for each CCP
4. Establish procedures to monitor each CCP
5. Establish corrective actions to be taken when monitoring indicates a deviation from the CCP limits
6. Establish record keeping for the HACCP system; and
7. Establish procedures to verify that the HACCP system is working correctly.

A CCP is “any point in the chain of food production from raw material to finished product where the loss of control could result in unacceptable food safety risk”. CCPs are monitored by the use of standards, which can be measured and evaluated on a regular basis. The applications of standards may be seen as a cost-effective substitute for product sampling and testing. This change in monitoring is especially important

for food-borne microbial pathogens, because their incidence is low and the cost of testing is high (Jensen, 2003). It is however important to notice that mandatory HACCP regulations are aimed at improving product safety, but not necessarily the final product quality.

The use of HACCP in food companies incurs two types of basic costs. The first category comprises costs associated with training, monitoring, record keeping, and testing. The second category includes costs of interventions to reduce pathogens that are incurred by food plants in order to meet some specified targets for reduction in microbial pathogens. According to Unnevehr and Jensen (2001) relatively little is known about these costs.

For several reasons it is difficult to evaluate benefits from mandated HACCP programmes. One reason is that there is no general agreement about the appropriate methodology for valuing suffering and loss of life (Buzby et al., 1996). Another reason is that there is no reliable information concerning the reduction in risk from mandating HACCP in an entire industry. The difficulties in measuring benefits imply that it may not be possible to find a regulatory standard that equates marginal costs with marginal benefits (Unnevehr and Jensen, 1999). It also implies that it is unclear whether the mandatory imposition of HACCP allows firms to meet food safety objectives in the most efficient manner or whether it is too prescriptive (Antle, 1998).

2.2. Risk assessment

The estimation of the costs of food safety based on HACCP implementation in the food industry assumes that the quantitative reduction in food hazards is measurable in the form of pathogen reduction or by the absence of a food safety problem. Therefore, an important step towards the estimation of costs associated with food safety improvements is to conduct a risk assessment which includes identification and exposure assessment as well as hazard and risk characterization. Unfortunately, most existing HACCP systems developed and used by food companies rest on a qualitative approach for hazard assessments implying that it is difficult to measure the exact occurrence of any specific hazards along the production chain and quantifying the economic effects of any control interventions. Developing and applying more quantitative tools for microbial assessment can be performed by using risk models, including epidemiological risk factor studies. Examples of quantitative risk assessment tools include Roberts et al. (1999), Hartnett et al. (2001), Rosenquist et al (2003) and Nauta et al. (2005b).

In the study by Roberts et al. (1999), a probabilistic risk assessment model is applied in US beef slaughter plants. Using Monte Carlo simulations, the computed average carcass contamination is modelled as the sum of four random variables associated with specific processes and expressed as \log_{10} colony forming unit (CFU) for a quantity of raw meat X . This is expressed as: $X = d + s + c + f$ where (d) is dehiding, (s) is steam pasteurization, (c) is chilling and (f) is fabrication. The amount of contamination reaching consumers is calculated as a distribution of contamination on an average raw hamburger. This is expressed as the average number of contaminants per burger in \log_{10} CFU, which is given by:

$$N = \log_{10} ((A * SA * (\%SA) * 10^x) / 8000)$$

where A is the number of animals contributing to a container package (a 2000 pound combo bin), SA is the surface area of the animal, and $\%SA$ is the percentage of the surface area that ends up in the container package.

Hartnett et al. (2001) in UK study used a Quantitative Microbiologic Risk Assessment model to evaluate the probability that a random bird selected at slaughter from the national poultry flock will be campylobacter positive, thus defining probability as

$$P_{pb} = P_{fp} \times P_{wfp}$$

where P_{fb} is the flock prevalence, i.e. the proportion of the national flocks that is positive and P_{wfp} is the within-flock prevalence of a positive flock at the time of slaughter. This risk assessment is focused on the rearing module that determines the risk-input at the slaughterhouse and how quantitative risk assessment can be adopted to obtain additional understanding of the infection pathway. P_{fp} is estimated from a composite of specific research studies from a couple of large individual farms weighted by their market shares and epidemiological studies using a beta-distribution. For the estimation of the P_{wfp} , Hattnett et al. (2001) used a two stage chain-binomial of epidemic spread, where the first stage refers to transmission from an infected bird to the cluster it belongs to and the environment represented by the drinking water and feeding. The second stage refers to the subsequent transmission of infection from the environment to colonization of the flock. The uncertainty is accounted for through the probability distributions attached to the parameter estimates prior to the model simulations.

Rosenquist et al. (2003) in a Danish study have developed a farm-to-table risk assessment model to estimate the exposure to campylobacter from chicken and the

number of human cases associated with the exposure. The model is composed of slaughter-processing and preparation-consumption modules. For the first module, information on flock prevalence of campylobacter, flock size and the chronology of 12 months flock deliverance to a Danish slaughterhouse were used as input data. In addition, information on initial concentration and changes in the number of campylobacter on carcasses during the processing stages from the literature was used as input data and to developed input data distributions. The risk model was designed to estimate the influence of four strategies; 1) a reduction of flock prevalence and reduction of the number of campylobacter positive flocks; 2) a reduction of the number of campylobacter on chicken carcasses; 3) a reduction of cross-contamination from positive to negative flocks during slaughter; and 4) a reduction of cross-contamination during food handling. The mitigation strategies are evaluated in terms of the fraction of *Campylobacter* positive chickens leaving the slaughterhouse; the number of *Campylobacter* on the birds; and the incidence of campylobacteriosis.

Nauta et al. (2005b)'s study from Holland contains a quantitative microbiological risk assessment by using a modular process risk model framework for a farm-to-table risk analysis. Their model describes the effects of inactivation and removal of the bacteria and the dynamics of cross-contamination where campylobacter is transferred from the intestine to the carcass surface and the environment and then in both directions between carcass and the environment. The model accounted for the variability between the number of campylobacter on the exterior expressed in cfu per carcass and the number of campylobacter in the leaking faeces in cfu per animal.

Activities have been initiated to disseminate information to the food industry about the applicability and benefits of quantitative risk assessment. One recent example is the Nordic Company Risk Assessment Network – CRAN. The objective of the network is to increase the knowledge of quantitative microbial hazard analysis in the Nordic food industries; and to develop computer-based tools to be used in quantitative microbial hazard analysis and decision making (Arinder and Borch, 2007). There is no doubt that a more widespread adaptation of quantitative risk assessment among food companies will give access to better data for economic analyses of food safety decisions and policies.

Quantitative risk assessments as those mentioned above may provide a useful input for risk management and communication. A study by Evers et al. (2003) illustrates how risk assessment can be linked with risk management, which involves the integration with economic models for policy analysis. The output of the exposure assessment

provides input to hazard characterisation, such that a dose-response effect model may be obtained for the pathogen in question. In the economic modelling the social and health effects of disease expressed as DALYS or disease-burden model are related to the cost in a cost-utility analysis. This projection forms the basis for the evaluation of intervention scenarios based on calculated cost and cost utility ratio for policy decisions (Mangen et al., 2005a).

2.3. Measuring food safety costs

Complete economic assessments of the net benefit of food safety improvements require cost estimates. Such estimates may show the cost of implementing new interventions by e.g. individual firms or a whole industry. Cost analysis of new regulation may also show how private incentives will be affected and thus the extent to which the costs may be compensated by higher product prices.

MacDonald and Crutchfield (1996) - referring to the Pathogen Reduction Hazard Analysis and Critical Control Points (HACCP) rule - examined some general principles of relevance for measuring the costs of food safety. These reviewed principles include universality, which refers to the inclusion of all costs. Among these are costs for enforcement, monitoring and compliance for the regulated entity. The other principles examined are incrementalism, which refers to marginal costs, treatment of transfers and substitution, causation, treatment of alternatives such as animal production and transport system, changing slaughter processing techniques and changing the preparation of food to reduce health risk for food-borne pathogens and the associated uncertainties.

Cost items in the control of food safety can be categorized in many alternative ways. In table 1 some examples of relevant cost items are shown (adopted from Unnevehr and Jensen, 2005).

Table 1. Examples of social cost categories

Social Cost category	General Examples	Food Safety
Real resource compliance costs	Capital costs of new equipment Operation and maintenance of new equipment Changes in production processes or inputs Maintaining changes in existing equipment Changes in input quality, such as skilled labour Changes in costs attributable to product quality; can be positive or negative.	Steam pasteurizer Additional water need for rinses Higher price of new pesticides More frequent cleaning Training of employees In HACCP procedures Lower quality of product with reduced pesticide use
Social welfare losses	Higher consumer and producer prices leading to changes in consumer and producer surplus Legal/administrative costs	Higher prices for crops with lost pesticide uses Higher prices for meat products Higher insurance costs against recalls
Transitional social costs	Firm closing Unemployment Resource shifts to other markets Transaction costs Disrupted production	Regional shifts in crop production Small meat processing shut down Reduced stock value due to recalls

Source: Unnevehr and Jensen (2005, Table 6.1., p. 108).

Real resource compliance costs are those costs that are incurred by individual firms in order to meet the food safety standards and other requirements in the food safety regulation. These costs can either be categorized as variable or fixed costs. Variable costs can be allocated to each unit produced, where some examples are operating labour and product testing costs. Fixed costs are either non-allocable costs or investments costs. An example of a non-allocable cost may be the training of the personnel in the HACCP producers. Purchase of new equipment like a steam pasteurizer is an example of an investment as the economic benefits incur over several years. It should also be noticed that it may be difficult to distinguish between these real resource compliance costs and other costs taken by the individual firm to improve the safety of its products. The reason is that there typically is a mixture of private and public incentives to improve the product safety. Many food companies may decide to market products with higher safety standards than required by the food safety legislation in order to harvest market opportunities.

The costs obtained by individual firms may result in some indirect costs, which are categorized as social welfare losses and transitional social costs, respectively, cf. table

1. Social welfare losses incur when companies may pass on extra food safety costs to the consumers by increasing the prices on their products, thus reducing their purchasing power and distort consumption possibilities, whereas transitional social costs may arise when food companies lose their ability to be competitive and thus go out of business. When measuring the welfare and transitional costs it is important also to consider the distributional effects and the adjustments made by producers over time. Allowing for adjustment over time is an important way for food companies to adapt to new requirements in a more cost-effective manner and neglecting such adaptation processes may incur higher real resource compliance costs in food companies than if they are allowed to adjust their production processes over a longer time period. Furthermore, depending on the type of food safety improvements the additional costs may be distributed differently between consumers and producers; e.g. if product prices are increased; between different companies, e.g. between small and large companies; and between different consumer segments, e.g. elderly people get more vulnerable to certain health risks. These distributional economic effects are often of greater magnitude than the direct compliance costs and thus important to account for in cost analyses.

The cost items to consider are determined by the selection of economic model for analysing the specified food safety problem. Three main approaches to cost analysis are described in the literature: the accounting approach, the economic-engineering approach, and the econometric approach (Antle, 2001).

Accounting approach

The accounting approach has been adopted in several recent studies of HACCP implementation. By this approach costs are calculated without estimating a parametric representation of the cost function. Typically data from single or a small group of companies are collected and used to calculate the higher labour costs incurred by increasing safety control or the extra capital costs by implementing new intervention technologies in the production process. See later Table 3 for examples where the approach has been used.

The accounting approach is straightforward to perform and can accommodate a rather high level of detail in the cost analysis. However, as noted by Antle (1999) among others there are many methodological shortcomings associated with the accounting approach. Firstly, using data from a single or a few companies will not depict the average costs of producing food products with specific quality and safety attributes nor will it give any information about cost differences between e.g. large and small firms.

Secondly, it does not provide any characteristics of the underlying cost function and hence the companies' room for adjustment to new interventions, e.g. product innovation, technological adjustments etc. In order to fully capture the economic effects of changes in the levels of quality and safety from imposing new regulations, statistical information about the cost function is of course necessary.

Economic-engineering approach

In this approach, detailed engineering data are combined with data on input costs to build a quantitative model of the production process. This process-based model of the plant's production function can be used to derive a parametric cost function. This approach provides a detailed picture of a plant's production process, but it is costly to implement for each plant studied. For an analysis of the costs of regulation in an industry with many distinct plants, the costs of using this approach for a large number of plants are usually prohibitive, so a small number of "representative" plants are typically modelled. By the economic-engineering approach it is difficult to account for the heterogeneity among companies and therefore this approach may not provide cost information that is representative for a whole industry. Table 3 in the next chapter provides some examples of the economic engineering approach.

Econometric approach

Econometrically estimated cost functions also can be used to measure the potential costs of food safety regulations. While these models usually cannot provide the level of process detail that is possible with accounting or economic-engineering models, they provide other advantages. Econometric methods are able to utilize large data sets that may be representative of a whole industry. Being based on the observed behaviour of plants in the industry, econometric models reflect actual production choices of plant managers. Econometric methods also provide a statistical basis to test hypotheses related behaviour and production structure, such as the hypothesis that the technology is joint in output and product quality (see later Table 3 in section 3).

2.4. The level of cost analysis

The costs of food-safety control have at least been investigated at six levels of aggregation as shown table 2.

Table 2. Levels of cost studies

Level of aggregation	Economic analyses	Methodological issues
Production process	Costs of individual intervention methods	Data collection Data verification Risk assessment
Plant/firm	Economic efficient combination of intervention methods Private incentives for improved food safety	Heterogeneity among firms Correlations between intervention methods Adjustment costs over time Process versus performance standards
Food chain	Interconnectivity Externality and incentive problems	Systemic approaches
Industry/sector	Regulatory costs Transaction costs	Cost of compliance Incentive structure Distributional effects
National	Costs of legislation Welfare costs	Regulatory impact assessment (RIA)
International	Costs of trade Effects of tariffs and non-tariff barriers	Fair trade issues

Process level

At the process level, the issue is which individual intervention methods should be adapted. In the literature there are many examples of cost studies of individual intervention methods. Examples of interventions available for pork include carcass wash, sanitizing sprays, steam vacuum, and carcass (hot water) pasteurizer (Jensen and Unnevehr, 2000; Malcolm et al., 2004; Vosough et al., 2006b).

Costs of technologies used to increase food safety in the product include both fixed (equipment) and variable costs. Data regarding costs of equipment and inputs required for operation may be obtained directly from suppliers of new technologies. Energy and water are the principal components of variable costs in meat processing. The study carried out by Jensen and Unnevehr (2000) shows that variable costs were highest for pasteurizers, followed by sanitizing spray systems, steam vacuum, and hog carcass wash. Total costs range from \$0.05 per carcass for washes at 55 C to nearly \$0.16 per carcass for hot water pasteurizers, and can be up to \$0.20 for high temperature washes of 65 C. This study also showed that the newer technologies have higher total costs than the older technology of low temperature carcass washing.

Plant level

From a plant perspective the challenge is to decide which set of interventions is the most cost-effective for achieving pathogen control. This involves two issues: a) how to control multiple pathogen targets; and b) where in the process to intervene (Jensen and Unnevehr, 2000).

Such economic decisions require information about: a) the structure of costs incurred by the firm in applying interventions to control food safety; b) data on the cost and effectiveness of selected food safety interventions in pork processing; c) an economic framework for choosing optimal sets of interventions.

At the plant level interventions are often used in combination for pathogen control, and such combinations may result in non-additive pathogen reduction. Thus, evaluation of alternative interventions would ideally include evaluation of combinations of interventions or use of interventions at different points in the process. However, those types of studies are unusual, and primarily focused on beef (Siragusa, 1995; Jensen and Unnevehr, 2000, p. 36).

Food chain level (systemic approach)

As a consequence of the increasing vertical integration and alignment in the food supply chain, it is becoming more important to understand the more integrated nature of food safety costs. Food safety failures are often systemic in nature. They arise because production systems and supply chains are characterized by interconnecting stages in production and inputs, and this interconnectivity gives rise to the technological potential for failures. Furthermore, incentive problems provide the economic potential for failures (Hennessy, Roosen and Miranowski, 2001).

Interconnectivity may also give rise to complementarities in input use (care in one area may increase the likelihood of taking care in other aspects of production). The presence of complementarities among activities means that there may be benefits that arise from complementary activities that cannot be assigned to the marginal productivity of any individual activity. A change in the cost for one activity is likely to move a whole cluster of complementary activities in the food production system, Jensen (2003). Baker (2007) addresses this issue by proposing an economic model framework for analysing food chain participants' economic incentives to provide foods with certain safety and quality attributes, based on mathematical programming.

It is unclear whether a systems-based approach is likely to lead to lower costs of food safety control than one based on controls in each stage of the process (Jensen, 2003). This requires that cost-benefit analysis can be integrated into farm-to-table risk analysis. Lack of access to the necessary data is probably the most important reason why there currently is so few cost studies published, which cover more than one stage of the entire food production chain. One exception is the action plan developed by Food and Drug Administration, Food Safety Inspection Service (FSIS) and the Plant Health Inspection Service in the US to eliminate *Salmonella enteritidis* (SE) illness caused by the consumption of eggs (Unnevehr and Jensen, 2005). The action plan was based on a risk assessment, which indicated that multiple interventions would be more efficient than would a single point of intervention in the reduction of the SE illness.

Another exemption is the study by Lund et al. (2004) who provide new knowledge of the costs and cost structures of producing and processing food products with specific quality and safety attributes. The costs of these differentiated products are compared and discussed with reference to some predefined standard food products. Only plant level costs are estimated, but this is done for additional stages in three different food supply chains. Thus, the obtained results may give new insight into the structure of production costs from a systemic chain perspective. Furthermore, this study may throw some new light on the intra- and interrelationships of the costs associated with food production and processing and hence identify where the additional costs of enhanced food quality and safety are appearing in the food supply chain.

HACCP was originally developed as a quality control tool in food processing that was sufficiently flexible to adapt to different firms, plants, or processes within plants. Its use as a regulatory standard to an entire industry or sector is different. First, its mandate should be linked to a system-wide risk assessment. This allows identification of the likely sources of hazards and the scientific basis for reducing them, so that regulation focuses on the most important sources of risk. Second, it may be explicitly linked with a particular regulated standard for food safety, which has implication for setting the limits of the critical control points (Unnevehr and Jensen, 2005).

The role of economics is important in adopting a systemic or chain-wide approach to food safety control as argued by Hooker (2000). If stage- or sector-specific risk management strategies are considered without the chain-wide determination of all economic implications, there is a risk that an inefficient policy may be selected, and/or significant disincentives will result. Similarly, examples of cost shifting among segments of the chain (transfers), as opposed to “true” cost reductions, may arise with the

application of HACCP-based systems (e.g., requiring more from your input suppliers via critical control points).

Sector level

Food safety assurance is at the heart at the sector level. The private sector has some strong incentives to prevent food safety crises and to mitigate their impact if they arise. Firms involved in a crisis may suffer from reputation lost, stock prices reduced, plant closed for cleanup or permanently shut down, food poisoning lawsuit filed, premiums raised for product liability insurance, and demand for product reduced enough to threaten entire markets or industries (Buzby et al., 2003). Among private approaches to food safety control are vertical integration, third-party certification and management approaches (such as HACCP systems and Good Agricultural Practices, GAPs).

Although the private sector has strong incentives to produce safe food, market signals to producers are imperfect. Consumers often cannot discern the safety of their food before buying it, and so their preference for safer food may not be reflected in the price they are willing to pay. Also, market transactions do not include all of the social costs of food safety (e.g., medical costs, lost work time). For these and other reasons private markets may not provide enough food safety because information costs are high, detection often very difficult, and the nature of the contamination is complex, which may give rise to food safety failures is the existence of externalities, or costs not borne by those whose actions create them (Jensen, 2003). Externalities tend to arise when strong dependencies govern relationships between economic agents, and when the production environment is not sufficiently well understood to allow market-based solutions (Hennessy Rossen and Jensen, 2002). Strong dependencies between agent decisions exist in the food supply chains. Microbial agents are widespread, can lead to significant hazards, are often difficult to detect, and can re-enter the food supply chain, even after control at earlier stages. When firms are not able to capture fully the returns from incorporating costly control of product hazards, they lack the incentive to implement production methods to assure a safer product (Jensen, 2003).

At the sector level there are also concerns that resources allocated for food safety control are not utilized in a cost-effective manner. For example, in many countries meat inspection is still based primarily on the organoleptic surveillance methods (i.e., sight, smell and touch). These methods are incapable of detecting disease-causing micro-organisms or chemical contamination. If laws require the control agency to inspect every animal carcass that passes through a slaughter facility, it is difficult to redirect

inspection efforts in ways that could be more efficient to minimize the most serious microbial and chemical hazards. Critics also cite the problems caused by processing technology advances such as higher-speed equipment, and new risks caused by pesticides, drugs and environmental contaminations not addresses by the inspection system (Antle, 1999).

National level

The goal of national food safety regulations is to mandate that firms produce safe products for consumers. The key reason why it is difficult to design regulations to do this, and why it is difficult to measure the benefits and costs of these regulations, is that food safety itself is difficult to measure. Information about the various quality attributes of food products is imperfect for consumers, producers, government regulators, and researchers, and this is particularly true when microbial pathogens are involved. These pathogens cannot be readily observed or tested in the production process, and their health effects are often difficult for consumers to identify after a product is consumed. Thus, a key challenge in modelling and measuring the benefits and costs of food safety regulations is to devise methods that can make the best use of the limited and imperfect data that are available. As recent experience with regulatory impact assessment in the United States shows, the currently available data provide, at best, highly uncertain estimates of benefits and costs of new regulations (Antle, 1999).

The use of performance standards may be part of a fundamental shift in regulatory philosophy and strategy. While command and control regulations prescribe how desired objectives are to be achieved, a higher reliance on performance standards will in general express the objectives but do not specify the means for achieving them. From an economic point of view it is believed that food safety and consumer protection can be achieved more effectively by establishing clear objectives in terms of performance standards, while proving the industry with flexibility to devise the best means of achieving the objectives, and then verifying through inspection and other forms of supervision that companies are meeting the established standards (Antle, 1999)

It is increasingly recognized by policy makers and the public that the existence of market failure does not necessarily mean that government regulations can improve upon the unregulated market, especially when one considers the positive role that market mechanisms such as liability and product quality reputation play in the provision of safe products, including foods. Moreover, even when some form of regulation can yield positive net benefits, experience in the field of environmental regulations has shown that the costs of regulations can depend crucially on how the regulations

are designed. Additionally, distributional consequences of regulations can affect their social desirability and their political feasibility, even if designed efficiently (Antle, 1999).

Another key factor that needs to be incorporated into the consideration of new food safety regulations is the dynamics of the adjustment period. The above discussion compares the design standards and performance standards in a static sense - before and after regulation. In reality, of course, firms implementing either design or performance standards will require time to learn how to incorporate new quality control methods efficiently. Therefore, the time path that regulations follow may have important implications for their implementation costs. For example, in the implementation of the HACCP and pathogen regulations, small plants are given several years more than larger plans to implement HACCP. This gradual phasing in of the HACCP regulations may significantly reduce the short-term adjustment costs associated with the regulations for these smaller plans. The issue of dynamic adjustment is also important in the ex ante estimation of regulatory costs. Economic models that do not incorporate the adaptability of firms over time as they adopt new safety control procedures may overestimate the impacts that the regulations have on costs of production after such adjustments have taken place (Antle, 1999).

International level

Trade in international markets may introduce additional costs for addressing and managing food safety hazards. Most internationally traded food poses no human health risks, with food safety incidents rare considering the total volume of trade. Trade disputes over food safety, however, can be persistent, and may require public intervention/investment and private costs to overcome (Buzby, 2003).

For food safety, the WHO's Sanitary and Phytosanitary Measures Agreement (SPS) makes specific reference to the "standards, guidelines, and recommendations established by the Codex Alimentarius Commission relating to food additives, veterinary drug and pesticide residues, contaminants, methods of analysing and sampling, and codes and guidelines of hygienic practice" as relevant (Swinbank, 1999). The growing use of HACCP as a sanitary standard in international trade has also led the Codex Alimentarius to adopt guidelines for HACCP in 1993, and to incorporate HACCP into food-hygiene codes starting in 1995 (cited from Unnevehr and Jensen, 1999).

In an area of increasing international trade developing countries have their specific problems. It is extremely costly to participate effectively in these international bodies,

let alone the SPS Committee. This is not just a question of airfares and subsistence, but of technical competence and backup. Developed countries might send a large team, comprising several experts; developing countries – if they are represented at all – may make do with one generalist. In this environment, rightly or wrong, the suspicion is that standards emerge which better suit the interest of the developed, rather the developing, would (Swinbank, 1999).

2.5. General features of cost analysis related to food safety

As a conclusion to the discussion in this chapter, the issues regarding costs and food safety vary according to the level of analysis – and so do the applied analytical tools, although many of them can be founded on some form of quantitative risk assessment.

Whereas at the process level, the issue is whether certain intervention methods are effective and low-cost per se, the issue at firm, plant, industry or chain level is rather, how to design a cost-effective combination of interventions and incentive structures in order to satisfy food safety standards in a economically feasible manner. On the other hand, the issue at society and international level will often be to specify relevant reduction goals and establish a suitable economic-institutional framework for such goals to be reached.

Hence, to a considerable extent, the concept of food safety costs is highly dependent on the specific context, and as a consequence, the appropriate choice of analytical approach and data will also depend on the context. The following chapters will provide an overview of currently applied methodologies in the literature, and will also address the the appropriate fields of application for these methodologies.

3. Costs and cost-effectiveness studies

3.1. Definitions and characteristics

Cost-effectiveness analysis is an economic approach used to compare different activities and actions aiming at the improvement of food safety. Cost-effectiveness analysis refers to the evaluation of monetized costs relative to outcomes that are expressed in units other than money (Drummond et al. 1999; Levin and McEwan, 2001). This is particularly the case for non-market goods such as food safety and other physical benefits. The physical benefits related to food safety are the number of averted adverse outcomes, e.g. mortality and morbidity hazards, which can be caused by a biological, chemical or physical agent in the food.

Essential features of cost effectiveness analysis are: 1) The existence of one unambiguous objective on interventions with a clear dimension along which effectiveness can be assessed, e.g. when we compare water rinses and decontamination during meat processing in terms of their cost per reduced pathogen prevalence. 2) The existence of many objectives but that the alternative interventions are expected to achieve the same level of effectiveness. For example if the use of sanitizing spray and steam vacuum both reduce prevalence and the intensity of infection to the same level. In this case, cost-effectiveness analysis is called cost-minimization analysis and is based on existing evidence of effectiveness (Drummond et al. 1999). However, because the costs have to be incurred in *ex ante*, i.e. before the evidence of effectiveness, the design of such studies is cost effectiveness analysis. In situations of multiple dimensions of effectiveness, they are assessed relative to each other or assessed; using common scores such as in Valeeva et al. (2007) or as cost-utility analysis such as in Mangen et al. (2005b). Assessing the incremental cost-effectiveness ratio ($\Delta\text{Cost}/\Delta\text{Effectiveness}$) might lead to the identification of dominant or extended dominant interventions i.e. intervention with both higher effectiveness and lower cost; or where the incremental cost-effect ratio for a given intervention is higher than that of the next most effective alternative (Drummond et al. 1999).

The improvement in food safety, which is the assurance that food will not cause any harm to the consumer when prepared and/or eaten according to its intended use (FAO/WHO, 2003), involves the control of mortality and morbidity hazards subject to different means or actions. The means and control actions may be located at many stages along the food supply chain (farm-to-table), which raises a number of issues. Following Caswell and Jensen (2007) such issues include:

1. At what points across the farm-to-table chain could interventions be applied to reduce the risk of food born illness?
2. How effective are the available interventions in reducing the risk of illness in terms of measures of adverse health outcomes?
3. What are the costs to government, industry and consumers of implementing the interventions?
4. Are there supply chain effects, i.e. changes in behaviour either up or down the supply chain from where the interventions take place, that will significantly influence the ultimate effectiveness of interventions being analyzed?
5. What are the costs and net benefits associated with different interventions?

3.2. The theoretical framework for cost and cost effectiveness analysis

The analysis of food safety regulation costs begins at the level of production process i.e. in farm and plant production units and requires consideration for production models that allow for quality-differentiated products (Antle 1999, 2000). The assumption is that there are markets for standard and safety improved food products with their corresponding market prices and production technologies. However, safety defined by the level of pathogenic contamination as a quality attribute can be difficult to price. Hence, the cost of its provision has implications for competitive pricing.

As a general rule, an economically efficient firm is interested in producing a given level of output(s) by combining inputs in such a manner that the total cost of production is at a minimum. Hence, an economic model for an effective firm can be formulated as:

$$\begin{aligned}
 & \underset{X_i}{\text{Min}} \sum_{i=1}^N C_i X_i \\
 & \text{st.} \\
 & f(X) = y
 \end{aligned} \tag{3.1}$$

where C_i is the costs incurred for inputs X_i and the sum of their products forms the objective function of the minimization problem. The production function $f(X)$, which represents the output level y , constitutes a constraint to the minimization problem.

From the standard properties of multiple output technologies, the quality of an output can be interpreted as the second output (q) of the production process (Antle, 2000b), implying that q enters the production function and the unit cost parameters. The main property of the multiple output technologies is the issue of jointness or nonjointness

of inputs. If inputs are nonjoint, then the cost of food safety can be estimated independent of the output productivities with respect to inputs.

In the food safety literature, the estimation of the minimum cost of interventions differs depending on available data and the approach adopted by authors. The estimation of the minimum cost can be performed by the use of a mathematical programming model as in (3.1) or by estimating an econometric cost function. Some authors focus on only the extra cost estimates associated with the provision of food safety (accounting approach). Some focus on combining accounting costs with the level of food safety produced (economic engineering approaches). Others focus on how the production of food safety affects the cost of production through the impacts on, or interaction with, other input factors (econometric approach). Yet others focus on the survival of firms hence assuming that firms that fail to produce at minimum cost make no profit and will exit from the market.

The accounting approach assumes that evidence of effectiveness exists. In contrast, the economic engineering approach combines accounting data with engineering data measured as effectiveness. Effectiveness is the outcome of intervention methods and may be generated through risk analysis, risk factor analyses or simulation models. Furthermore, the approach provides the possibility of generating cost-effectiveness ratios, least cost frontier curves and optimised least cost combinations, which are then used for economic evaluation and the ranking of alternative actions. In the literature, both approaches are concerned only with the extra costs associated with intervention actions, hence assuming that the impacts of interaction between food safety intervention actions and production inputs are zero. The economic engineering approach when estimated using mathematical programming has the advantage of imposing a series of constraints that lead to investigating the impact of interventions on desired food safety levels.

The cost estimates for the above approaches are the sum of tabulated costs TC (e.g. the sum of annuities for fixed capital investments A, plus variable expenses VC) per intervention action m (Jensen et al., 1998, Mangen et al., 2005b, Vosough, 2007). The costs are generally represented as:

$$TC_m = A_m + VC_m \quad (3.2)$$

Fixed capital investments are generally depreciated and discounted following standard economic principles and include the costs of purchase of equipment, installation

and expenses associated with reorganisation. Variable costs are related to annual maintenance and volume dependent activity expenses.

Partial budget cost calculation has the general format of four categories, which are additional returns (AR), reduced costs (RC), returns foregone (RF) and extra costs (EC). The net costs are calculated as $(RF + EC) - (AR + RC)$. For example, Van der Gaag et al. (2004) and Valeeva et al. (2007) have used the partial budgeting method to estimate the cost of food safety interventions.

The solution to the optimization problem (3.1) can be expressed as a cost function. The econometric approach estimates the cost function or derivatives thereof. An example of the variable cost function is provided in Antle (2000b), who investigated the impact of food safety regulation on the cost of production, distinguishing three outputs: output quantity, product safety and a vector of non-safety quality attributes. Food safety is produced in the meat and other food industries through the use of various quality control technologies, including product inspection, process control, and the HACCP technology required by regulation, product testing and identity preservation.

The representation of quality in the cost function emphasises that quality is endogenous (chosen by the firm) and correlated with exogenous variables in the firm's cost function (Antle, 2000, following the work of Gertler and Waldman, 1992). The implication is that when evaluating the costs of food safety improving interventions, quality adjustments should be taken into account - otherwise cost estimates will be biased (under estimated).

3.3. Studies and results

Examples of cost and cost-effectiveness studies grouped by the level of study along the food producing chain, food safety measures considered and applied method as well as the focus and the types of costs investigated are provided in Table 3. The examples column in the table identifies the individual studies and the source of data whiles the column of control measures investigated seek to identify the intervention actions considered. The methods column identifies the approach and how costs were calculated or estimated. The focus column identifies the economic evaluation under consideration and the types of intervention costs are given for resource compliance (C), social (S) and transitional (T). Finally, the last column identifies the effectiveness output to which interventions were compared.

Table 3. Examples of food safety costs and cost-effectiveness studies grouped according to chain level, control actions focus and measure of effectiveness

Chain level	Examples	Control measures Investigated	Methods	Focus and types of costs ()	Measure of effectiveness
Farm	Dorn and Bachmann (2000) in a German study estimated the costs of hygiene for dairy farms. Data is based on documents and survey interviews of managers of 7 farms.	Animal-hygienic measures	Accounting	Costs (C)	None
	Mangen, Havelaar and Poppe (2005) to reduce the level of uncertainty used a Monte Carlo simulation to estimate the costs of food safety intervention actions on broiler farms for the Dutch CARMA project (Campylobacter control in chicken). Data for initial values of interventions were based on literature, the epidemiological studies conducted by Bouwkniet et al. (2004) and from the Dutch central bureau of statistics.	Interventions (Farm-hygienic measures, phage therapy and PCR-tests)	Accounting (Annuity, Simulation with distributional output)	Costs (C)	None
	Valeeva et al. (2007) , in a Dutch study, estimated an objective optimization problem using Integer Linear Programming to identify the cost-effective activities or actions for increasing levels of food safety defined simultaneously for chemical and microbiological contamination on dairy farms. Cost data was collected through personal interviews of stakeholders and calculations using production assumptions for the farm size of 50 and 250 dairy cows	Interventions: covering 28 actions, related to incoming feed, herd, pasture and water management as well as personal hygiene, maintenance and participatory in performance schemes	Economic-engineering (Partial Budgeting)	Cost-effectiveness (Least cost optimal choice) (C)	Point-Scores for increasing food safety estimated from Adaptive Co-joint Analysis based on expert opinion
Process plants	Zaibet and Bredahl (1997) , in a UK study investigated the effect of private standard scheme for food quality and safety on transaction and production cost within the beef industry and hence on social welfare. The data is simulated with estimates from literature.	Intervention is the ISO 9000 based principle.	Econometric (estimates from demand-interlink models)	Costs (S)	None
	Klein and Brester, (1997) in a US study , estimated a cost function to investigate the effect of zero pathogen tolerance directives on US beef plants. Hence tested if the cost of food safety is joint with rest of the production process. They used time series data for 5 plants for the years 1988 through 1995.	Intervention is the amount of down time on production lines due to the zero pathogen tolerance directives.	Econometric (Translog costs function)	Costs (C)	None
	Jensen, Unnevehr and Gomez (1998) illustrated the costeffectiveness analysis for US beef and pork processing sectors. The tabulated sum of fixed and variable cost data for the interventions was collected from supplies. The data for reduction in E.coli, Salmonella and Listeria, was provided by Phebus et al. (1997) and Dickson (1997) .	Interventions: The paper evaluated eleven single or combinations of pathogen reducing technologies.	Economic-engineering	Cost-effectiveness (Least cost curves) (C)	Log ₁₀ CFU reduction in bacteria counts
	Jensen and Unnevehr (2000) , paper demonstrated the application cost minimization optimisation model to identify the cost efficient interventions methods for reducing 2 pathogens, aerobic bacteria (TAB) and enterics (TE) in US pork plants. The cost data was provided by service industries and the effectiveness data was provided by Gill Bedard and Jones (1997) and Dickson (1997) .	Interventions: Cover three single or combinations hereof of water rinse at three temperatures as well as carcass pasteurization	Economic-engineering	Cost-effectiveness (Least cost optimal choice) (C)	Log ₁₀ CFU reduction in bacteria counts

	Antle (2000) in a US study, estimated a variable cost function to examine if the provision of improve food safety affects the productive efficiency of beef and pork processing plants. The data is collected from the US manufacturing database.	Intervention is an assumed efficacy level	Econometric (Translog variable costs function)	Costs (C)	Non (efficacy assumed)
	Boland, Hoffman and Fox (2001) estimated the costs associated with development and implementation of HACCP, SSOP, Salmonella Performance standards and E.coli Process Control testing for small meat and poultry plants in US Great Plains. Data was collected from a survey of 18 meat and poultry plants, The data is detailed on the cost components of actual implementation of the intervention actions.	HACCP and SSOP systems, Salmonella and E. coli control	Accounting	Costs (C)	None
	Ollinger and Mueller (2003) in a US study estimated a cost function to investigate the effects of existing private sanitation and control practice deficiencies (food safety actions) on plant cost.	Interventions are sanitation and process control practices (SPCP)	Econometric (Translog costs function)	Costs (C)	None
	Malcolm et al. (2004) in a US study used a decision model to evaluate the cost and effectiveness of seven combinations of pathogen-reducing technologies on the beef slaughter line of a cattle slaughter plant. The data on effectiveness was from a Monte Carlo simulation of a probabilistic risk analysis model (Roberts, Malcolm and Narrod ,1999). The cost data is the USDA estimates based on industry and manufacturing estimates, irradiation cost estimates are from Morrison Buzby and Lin (1997) .	Interventions covered three and the combinations hereof of pathogen-reducing technologies, dehiding, steam pasteurization, and irradiation.	Economic-engineering	Cost-effectiveness (Least cost trade off frontier curve) (C)	Log ₁₀ CFU bacteria reduction in combo-bin beef hamburger patty,
	Mangen, Havelaar and Poppe (2005) used a Monte Carlo simulation to estimate the costs of food safety intervention actions in slaughterhouses for the Dutch CARMA project (Campylobacter control in chicken). Data for initial values of interventions were based on literature, the risk factor and risk analysis studies conducted respectively by Bouwkniet et al. (2004) and Katsma et al. (2005) .	Interventions (Along the processing and distribution stages)	Accounting (Annuity, Simulation with distributional output)	Costs (C)	None
	Vosough et al. (2006b) explored the rank of intervention actions against pathogenic E.Coli, in commercial beef plants. The effectiveness data is an epidemiological-simulation model (Vosough et al., 2006a). Cost data was collected from literature, experts from 3 Dutch industrial slaughterhouses and the internet	Interventions covered 7 carcass decontamination methods.	Economic-engineering (Annuity)	Cost-effectiveness (Ratio and Least cost frontier) (C)	Prevalence per quarter of carcass
	Muth, Wohlgenant and Karns (2007) explored the impact of 1996 pathogen reduction HACCP regulation on meat and poultry slaughter plant exit during implementation and post implementation compared to pre-implementation. Data was collected from the Food Safety Inspection Service industry surveys for 1993, 1996, 2000 and 2003.	Interventions (captured by time period)	Econometric (Probit model of survival)	Costs (Lost profit) (T)	None
Supply chain	Van der Gaag et al. (2004) explored the cost of different intervention methods against salmonella contamination along the chain defined as the finishing, transport lairage and slaughtering stages The cost data was from the Dutch Quantitative Information from Animal Husbandry research institution, scientific literature and interviews. The effectiveness data was from an epidemiological simulation model for pork supply chain.	Intervention	Economic-engineering (Partial Budgeting)	Cost effectiveness (Ratio) (C)	Prevalence per stage and Prevalence per carcass (chain)

Mangen et al. (2005b) in a Dutch study combined cost data for interventions for farm and slaughter process (Mangen, Havelaar and Poppe, 2005). Marketing data from Product Board for Poultry Meat and Eggs combined with consumer cases of campylobacteriosis (Nauta et al., 2005a) and cost of illness estimates of DALY adjusted at 4% to explore the cost-effectiveness and cost utility of food safety interventions	Interventions (Along the chain)	Economic-engineering (Annuity, Simulation with distributional output)	Cost effectiveness (Ratio) Cost Utility (Ratio) (S)	Campylobacteriosis cases per year; Disability Adjusted Live Years (DALY)
Valeeva et al. (2006) used integer linear programming to identify the least cost combination of food safety improving actions within the Dutch dairy chain, which includes the feed companies, farms and dairy processing stages or blocks. Increasing food safety is defined simultaneously for chemical and microbiological hazards as point scores based on expert perceptions. Cost data on intervention actions for feed and processing companies were collected through interviews with company representatives. However cost data from farms was obtained from handbooks and reports e.g. from the Research Institute for Animal Husbandry. The cost were standardized for a specific production structure.	Intervention	Economic engineering (Partial budgeting and annuity calculations)	Cost effectiveness (least cost combination) (C)	Point-scores
Vosough et al. (2007) , Data from an epidemiological simulations for Dutch Dairy farms was used to update the slaughterhouse plant model (Vosough et al. 2006a) for output of effectiveness and combined with intervention costs for farms as well as the cost for slaughterhouse model (Vosough et al. 2006b) to explore the cost-effectiveness of interventions.	Interventions, covering 4 actions on farms and 7 at slaughterhouses and their combination hereof	Economic engineering (Partial budgeting and annuity calculations)	Cost-effectiveness (Ratio and Least cost frontier curve) (C)	Prevalence per stage and Prevalence per carcass (chain)
() Types of intervention costs: (C) is real resource compliance, (S) is social, and (T) is transitional.				

Results from cost effectiveness studies

The results among the cost-effectiveness studies suggest that increasing food safety induces higher marginal costs for meat processing plants. However, the costs are modest and account for about 1 to 2 % of plant costs (Jensen, Unnevehr, and Gomez, 1998; Unnevehr and Jensen, 1999; Jensen and Unnevehr, 2000). It was also found that: 1) Pathogen reduction technologies might not be pathogen specific hence might affect multiple pathogens. The implication is that pathogen reduction involves substitution and complementary multi control costs. 2) The major uncertainty surrounds cost increases associated with firm modification or adoption of new processes to control microbiological pathogens. 3) Implementation of food safety improving interventions have economics of scale that favours large firms in US studies (Unnevehr and Jensen, 1999; Malcolm et al., 2004); although Mazzocco (1996) implied that small firms might gain operating efficiency through better organization of labour or processes.

Jensen and Unnevehr (2000) in the US study of the cost-effectiveness of different technologies for pathogen control in pork processing plants used the economic-engineering approach. The engineering data obtained from input suppliers of new control technologies were used to construct comparable operating and depreciation costs. Formulating and solving a non-linear programming model they estimated the optimal cost-effective combination of interventions to meet a set of predetermined safety standards. By stepwise tightening the safety standards, marginal cost functions are derived (see figure 1 in Jensen and Unnevehr, 2000), which show that intervention costs rise steeply as the desired pathogen levels approach zero.

Mangen, Havelaar and Poppe (2005) and Mangen et al. (2005b) in Dutch studies found that the total cost for provision of extra hygiene measures, phage therapy and PCR-tests would cost broiler farms €0.05 per bird but the provision of extra hygiene measures alone ranges between €0.02 to 0.16 per bird.

Valeeva et al. (2007) in a Dutch study suggest that costs for dairy farms increase at increasing level of food safety irrespective of farm size. Small farms are more cost-effective with the choice of intervention actions at low desired levels of food safety compared to large farms. The cost-effectiveness of large farms at high food safety levels contributes more to desired food safety.

In general, it is suggested that: 1) A HACCP programme needs to be tied to verification that it is actually reducing food safety risks in order to be used as a substitute for

performance standards also in international trade. 2) To attain high food safety levels it is proposed to assess the whole food chain system. It is emphasised that food prices and availability for consumers are rarely the issues in regulation impacts, which partly due to shifts in supply to other regions and partly balancing past cost and benefit of regulation. 3) Regulation has impact on long run incentives to invest in new technologies and therefore likely to bias productivity growth. Hence, analysing cost is a prerequisite for choosing among alternatives. A risk-based system can be the best way to understand cost incentives and risk outcomes resulting from different alternatives (Unnevehr and Jensen, 2001).

Meuwissen et al. (2003) proposed the needs for economic design of traceability systems, analysis of the distribution of costs and benefits of traceability along the production chain and the optimisation of incentives for participating in traceability systems. In addition, they proposed the reconsideration of the liability and recall-insurance schemes as well as communication about food-safety-related systems and certification with consumers to be in line with the EU food-safety hygiene rules of regulatory standards at country level and systems at company and chain levels.

Results from cost studies

A number of econometric studies have been reported in the literature. For example, Klein and Brester (1997), who estimated a translog-function, to analyse the effects of USDA's "zero-tolerance directive" on the cost of production in beef slaughter plants. Antle (2000) who estimated an econometric cost function models to investigate the impact of food safety regulations on the cost of beef, pork and poultry production. Although econometric modeling in general cannot accomplish the same detailed cost information as the accounting method, it provides the opportunities of statistical testing of hypotheses related to the economic behavior and the underlying production technology.

Klein and Brester (1997) in their US study found that the zero tolerance directives for improved food safety affects the productive efficiency of the plants by increasing costs to around 30 billion dollars, which plant managers however expected to fall over the years. On the other hand, Zaibet & Bredahl (1997) in a UK study found that that the cost of ISO certification is minimal. Both producers and consumers gain, but producer gains from the ISO certification are sensitive to the elasticity of substitution between inputs.

Antle's (2000) study of US beef, pork and chicken slaughter and processing plants was designed to estimate a variable cost function and test for jointness of output and quality, using plant-level data. Antle showed that the cost function can be estimated by combining a hedonic model with a cost function model to account for the fact that product quality is not observable. His analysis rejected the hypothesis that output and quality are non-joint. It also revealed that cost of production is increasing with product quality, which may imply that more stringent food safety regulations will result in higher costs of production. Furthermore by stratifying the data into small and large plant size groups, it was shown that the potential regulatory costs per unit faced by small beef plants were similar to the costs of large beef plants. Ollinger (1998) used US Census of Manufactures data to estimate total cost functions for beef, pork and miscellaneous meat products. Ollinger's study confirmed that higher product safety is associated with a higher cost of production.

The cost function model developed by Antle (2000) can be used to estimate food safety costs incurred for imposed performance standards: 1) Using the existing technologies 2) When changes in technologies (equipment modification and change in capital stock) are required e.g. using pre and post data for the estimation, respectively; 3) When changes occur in the capital stock without process modification, i.e. the estimation of the change in fixed cost function. In addition, food safety costs can be estimated for standards – either alone or together with performance standards as in the pathogen reduction HACCP regulation (Antle, 2000b).

Antle (2000) found that if regulative intervention actions are 100% effective in pork plants, variable production costs would increase by 5 to 50 US cents per pound depending on the base level of safety in the plant. For an extrapolation of safety improvement of 20%, additional cost of 1 to 9 US cents per pound product will be incurred. Furthermore, Antle found that within beef and pork plants regulatory impacts on small and large plants do not differ, whereas among the poultry plants, small plants impact is 1 cent higher per pound than on large plants. Antle pointed out that these cost estimates represent only the impacts of regulation on operation efficiency. Hence if added to the quality control costs estimated previously by FSIS the cost of food safety will plausibly exceed the FSIS estimated benefits.

Fox and Hennessy (1999) in contrast to Antle (2000) developed a theoretical biological-driven microeconomic model in order to investigate the trade-off between intervention costs and economic damage. Both fixed and variable costs of intervention are included in the estimated private cost of food contamination, which is represented by

the stochastic rate of contamination and the growth rate of contaminants using a Poisson process. The model is designed to study repeated interventions in time space to control pathogens, and to study regulation through fines where thresholds are functions of pathogen biological parameters so that there is no need to observe actual incidence. Under the assumption that contamination occurs randomly and uncontrolled, pathogens often grow at an exponential rate. The Poisson process is converted into a private economic loss of uncontrolled contamination as a function of time. The model of Fox and Hennessy is set to identify the number of economic optimal points of a HACCP system and investigate the impact of fines, which are associated with random and terminal inspections. It is worth noting that Antle (2000) as well as Fox and Hennessy (1999) suggest that the costs of food safety can be estimated without the knowledge of the incidence of food safety.

Ollinger & Mueller (2003) in US study estimated the marginal impact of food safety, defined as percent deficient sanitation process control practices (SPCP) on plant cost and found that SPCP on average raised plants' costs. However, cost increase for the involving plants in the study, is not significant. But technology and market variables as well as percent deficient SPCP were suggested to affect plant survival rates. Hence plants with severe SPCP problems are likely to exit due to food safety process control performance. Thus, it is implied that stringent pathogen reduction HACCP rule enforcement will result into increased plant exit rates. The authors also showed how the costs of HACCP could be projected from the costs of SPCP.

Ollinger & Ballenger (2003) discuss the cost of food safety in term of costs associated to food recalls and liabilities and further in terms of direct investments in food safety and survival or exit from business. They also suggested that due to these potentially high costs for food safety, industry has taken steps to improve food safety.

State-of-the-art on cost and cost-effectiveness methods

As demonstrated in this chapter, there exists a number of approaches to analysing costs and cost-effectiveness in the field of food safety strategies – varying from relatively specific interventions to broader strategies. From a methodology point of view, most of the mentioned studies can be considered as based on either an accounting approach, an economic-engineering approach or an econometric approach. Studies within the economic-engineering and the econometric approaches are generally based on an economic optimization assumption, where firms' possible adjustments to food safety interventions are assumed to be motivated by economic incentives.

Many of the considered studies based on the economic-engineering approach build on a stochastic risk assessment framework describing the effects of the interventions, and supplements these frameworks with assessments of the costs associated with the interventions. This yields the opportunity to take into account the stochastic nature of microbiological food safety, however at the cost of a relatively high degree of complexity and also a relatively high degree of specificity.

The studies referred to in this chapter analyse the costs of food safety improvement without considering the value of such food safety improvements. In the next chapter, some of the issues related to the valuation of these improvements – and the literature dealing with this aspect - are discussed.

4. Microbiological food safety and cost benefit analysis

From a policy perspective, reliable estimates of the benefits and costs are required to guide the selection between alternative measures to improve food safety. Whereas the balance between private benefits and costs matter in a company perspective, the question from a society point of view is whether the benefits from a given improvement exceed the costs and how this improvement is ranked relative to other possible improvements that could be made with the same resources, in a broad society perspective (Caswell, 1998).

The general idea in cost benefit analysis is to weigh costs and benefits associated with a strategy S against each other, often in a present value calculation:

$$W_0^S = \sum_{t=0}^T \frac{1}{(1+\rho)^t} \cdot B_t^S - \sum_{t=0}^T \frac{1}{(1+\rho)^t} \cdot C_t^S \quad (4.1)$$

where B_t^S represents the value of benefits obtained due to the strategy in period t, C_t^S represents opportunity costs of resources devoted to the strategy in period t, and ρ is the rate of discounting. Compared to cost effectiveness analysis, cost benefit analysis poses two additional challenges in terms of valuation of non-monetary benefits and costs and discounting.

The range of costs involved in strategies to obtain higher level of microbiological food safety include investment and operating costs in various stages of the food supply chain, cf. section 3. Furthermore, the costs may include costs of administration and monitoring – e.g. at the firm, consumer or authority level – in monetary as well as non-monetary terms.

Benefits associated with food safety strategies include direct benefits for consumers (improvement of consumers' health, lower health risk etc) as well as avoidance of external costs (health care costs, loss of working days, expenditures related to averting behaviour by consumers to avoid risky products). Furthermore, food producers can obtain benefits from such strategies in terms of better reputation and better access to foreign markets (Caswell, 1998). Whereas some of these benefits (especially those of a direct nature) will be more or less reflected in market prices and hence may be measured through these market prices, the external benefits (prevented external costs) are normally not valued in the market. Furthermore, imperfections in e.g. information may imply that even benefits of a direct nature may not be fully reflected in the mar-

ket prices. To the extent benefits are not reflected in market prices, there may be a case for public intervention. Cost-benefit analyses may reveal the extent of such external benefits relative to benefits that are internalised in market prices. Furthermore, there may be cases where the costs of public versus private interventions differ (Unnevehr, 1996). Cost-benefit analyses may reveal whether private or public interventions are the least costly relative to obtained benefits, and thus which type of intervention should be selected.

The issue of *discounting* concerns weighting and comparing costs and benefits at different times. For example, if a strategy to reduce the pathogen level in meat requires substantial initial investments, but leads to reductions in the pathogen level for 20 years, how should the value of these reductions be weighted against the initial investment?

This chapter deals with different approaches to valuation of benefits related to food safety, as well as the use of these methods in applied cost-benefit analysis.

4.1. Analysis of costs to society: methods, problems and findings

From an economic point of view, costs represent the opportunity costs to society, that is what society gives up by applying resources to meet a regulation (MacDonald & Crutchfield, 1996). For many applications (depending on the extent of the regulation), it is most relevant to apply a marginal approach, i.e. the marginal benefits and costs associated with a given regulation.

Costs of achieving improved food quality may result from quality assurance programmes that are adopted voluntarily by producers (in order to improve market position, meet customer standards etc.) or may be adopted as a result of government regulations. Clear cost accounting is essential to identifying, describing and measuring changes in production (within company), transaction (between companies) and regulatory compliance costs associated with adoption of quality management systems. In quantitative analyses of government requirements, it is also necessary to distinguish between observed overall costs to meet the regulation, what the costs would have been to meet minimum government requirements, and incremental costs attributable to the government requirements (Casswell, 1998).

Several key components of the cost-benefit framework need to be understood when applying the approach: universality (the need to take all relevant costs into considera-

tion, including enforcement, monitoring and costs of compliance), incrementalism (i.e. additional benefits and costs generated by variations in the stringency of a proposed rule), identification and treatment of transfers and substitution (focus on the use of resources, ignore transfers and take into account substitution effects), causation (focus only on costs and benefits caused by the regulatory change), treatment of alternatives (choice of relevant reference/benchmark) and uncertainty (how certain are the estimates of costs and benefits) (MacDonald & Crutchfield, 1996).

In order to establish adequate cost-benefit comparisons, it is necessary to have representative, detailed cost data which can be linked to actual microbiological (or other) improvements solely due to the particular strategy under review. In this way, one can avoid (or at least minimize) the potential for confusing the causality issue (Hooker, 2000).

Costs of HACCP implementation in meat production include labour costs for record-keeping, record review, plan development etc., along with costs of material, equipment and testing costs. However, there appears to be some disagreement among studies concerning the required effort in collecting test samples, as well as concerning the effectiveness and costs of various process modifications, and these assumptions play crucial roles for the magnitude of the estimated costs (Roberts et al., 1996, Crutchfield et al., 1997).

In addition to the direct costs and/or cost-savings involved in specific measures, account should also be taken to a number of side-effects, including scale effects, impacts on non-safety quality attributes, reduced variability in product quality, increased transparency with regard to international trade, potential first-mover advantages arising from the use of innovative food safety controls (Hooker, 2000). Furthermore, it should be taken into account that ex ante evaluations of food safety interventions often may be biased, because they cannot take full account of e.g. behavioural adjustments, development of new food safety technologies, developments in firm structure, as well as interactions with other economic sectors. Antle (2000) has obtained econometric cost function estimates suggesting considerable efficiency losses due to US HACCP regulations. Cao et al. (2005) have adopted a similar approach for New Zealand leading to similar results, and Goodwin & Shiptsova (2002) use an equilibrium displacement model to analyse survey data, also suggesting considerable economic losses for the food producers involved. Golan et al. (2000) develop an approach for determining economy wide effects of HACCP regulation taking into account the interaction between sectors using a Social Accounting Matrix (SAM) ap-

proach, suggesting that a significant share of the direct costs related to the considered HACCP-programme may be offset by gains in other sectors of the economy.

4.2. Valuation of benefits - methods, problems and results

Benefits of improved microbiological food safety include both private and public benefits. Public benefits include reduced cost of illness, loss of productivity and loss of life. From a business perspective, private benefits from reducing the prevalence of pathogens may include improvements in shelf life, retention of existing customers, access to new (e.g. export) markets, decreased scrap or reworking of products and reduced product liability (Jensen and Unnevehr, 2000). Furthermore, from a consumer perspective, benefits from reduced pathogen risk may include reduced costs of averting contaminated foods and higher product confidence.

Two overall approaches to valuation of benefits related to food safety exist: the human capital approach, where benefits in terms of reduced health risk is measured in terms of the gained expected lifetime earnings and activities, and the willingness-to-pay approach, where people value risk reduction if it leads to a greater level of welfare (Shogren et al., 2001). In general, existing methods to value the benefits associated with improved food safety rely on a marginal perspective. Hence, they assume that existing equilibrium prices in markets relevant for the valuation will not be affected by the improvement (for example, that the equilibrium wage rate will not be affected by reduced disease frequency as a result of improved food safety). However, Van Ravenswaay and Hoehn (1996) propose some theoretical considerations about how to incorporate different types of consumers' behavioural responses into the analysis.

A number of methods to valuation of benefits of food safety have been developed through the last couple of decades, including

- cost of illness approaches
- direct willingness-to-pay studies
- conjoint analyses
- valuation through market prices
- liability costs methods

The *Cost of Illness (COI)* approach measures the benefits of an improvement (e.g. improved food safety) by the value of avoided illnesses, deaths, losses in income and leisure, pain and suffering (Caswell, 1998). The use of the COI approach within the

field of food safety has been developed by Roberts (1989). Whereas other measures of disease burden (Disability Adjusted Life Years – DALY - or Quality Adjusted Life Years – QALY) evaluate impacts on mortality and morbidity in terms of change in number of years¹, the COI method evaluate the effects of interventions on disease burden in monetary terms as the effects as changes in medical costs and productivity loss. Various alternative approaches to the valuation of disease burden and disease risks have been reviewed and discussed by Kenkel (2001), who makes the point that valuation of statistical lives for similar risks should be consistent across applications (but also that the values of different risks should differ).

The COI approach has been applied in a number of studies regarding pathogen-related food safety, including Buzby et al. (1996), Crutchfield et al. (1997), Roberts et al. (1996) and Korsgaard et al. (2005). Although the studies share the basic COI approach as a point of departure, they also differ in various aspects. For instance, some studies include the value of deaths, whereas other studies do not. Some main results from these studies are summarised in Table 4.

Buzby et al. (1996) is a key reference with regard to the quantification of disease costs from bacterial foodborne diseases. The study provides a detailed analysis of the risk of acute and permanent disease problems or deaths caused by infection of various pathogens, including salmonella, campylobacter, E.coli and listeria, and associates treatment costs with these diseases and a value of statistical life to deaths. The study has formed the basis for many of the subsequent evaluations of food safety enhancing interventions in the United States, including Roberts et al. (1996), Crutchfield et al. (1997), Golan et al. (2000), Goodwin and Shiptsova (2002). For example, Golan et al. (2000) have used the COI estimates by Buzby et al. (1996) in a SAM analytical framework to investigate the economy-wide effects of reduced food-borne illness, finding that such reductions lead to an economic loss from an economy-wide perspective, because consumption of medical goods and services caused by foodborne illness triggers more economic activity than the consumption activities that households would have enjoyed if they had not become ill.

¹ Mauskopf & Morales (2001) provide a review of such studies, distinguishing between “top-down” (based on aggregate information about number of disease cases) and “bottom-up” studies (based on estimates of exposures and dose-response relationships). Furthermore, Mauskopf & Morales develop a method for combining different health outcomes into an aggregate QALY measure.

Mangen et al. (2005a) provide a study on the COI of campylobacter in the Netherlands, whereas Korsgaard et al. (2005) (cited in Andersen and Christensen, 2004), provide a Danish COI study of salmonella, however not including death risk.

Table 4. COI benefit estimates of reduced pathogen incidences			
Reference	Disease	Country	Cost estimate
Buzby et al (1996)	Salmonellosis	US	908 1993-US\$/ incident
Buzby et al (1996)	Campylobacteriosis	US	468-550 1993-US\$/ incident
Buzby et al (1996)	E.coli	US	15.000-18.000 1993 US\$/ incident
Buzby et al (1996)	Listeriosis	US	63.000-69.000 1993-US\$/ incident
Korsgaard et al. (2005)	Salmonellosis	DK	671 DKK/ incident
Mangen et al. (2005a)	Campylobacteriosis	NL	255€/incident

Cost-of-illness estimates may be considered as a lower-bound estimate of benefits, because they do not include averting and avoidance costs (Van Ravenswaay & Hoehn, 1996). This is supported by Kenkel (2001), who finds considerably higher estimated value of statistical lives, if they are valued using WTP methods than if studies are based on human capital assessments. On the other hand, COI-estimates include health costs that are not paid by the consumers – costs that would not be captured by valuation studies.

Unnevehr (1996) discusses the challenges in cost-benefit evaluation of information interventions and points to the fact that a complete framework to evaluate information interventions would include the cost of such interventions relative to their benefits and relative to alternative interventions. She proposes that one way to capture the effects of information might be to study consumers’ averting and avoidance cost and to include the cost of information into these costs, and to estimate the effects of interventions on this information cost.

Direct willingness-to-pay approaches use consumers’ statements about their willingness to pay for lower health risk in general or for specific safety attributes in foods. Such studies may rely on open-ended questions about the willingness to pay (e.g. contingent valuation methods). However, during recent years, methodologies using real or virtual choice experimental data, where test persons are asked to choose between commodity varieties with different levels of e.g. the food safety, price and possibly other attributes, are in use. Hence these choices can be analysed statistically. Examples of this approach include Christensen et al. (2006), who use virtual choice experiments to reveal consumers’ willingness to pay for labelling of campylobacter-free

chicken (around DKK 20 per chicken) and their trade-off between food safety and animal welfare, or Hayes et al. (1995) who used real choice experiments to explore the willingness to pay for safer food and found that on average willingness to pay for safer food is approximately 0.70 US\$ per meal. Although such studies attempt to reflect the choices to be made by consumers, they are not based on real shopping situations where consumer choices are actually binding. Hence, these methods are subject to some uncertainty and potential bias, due to e.g. participants' lack of familiarity with the experiment situation, anchoring bias induced by initial posted prices, or differences between the experiment setup and a real shopping situation (Shogren et al., 2001).

Another – more qualitative - methodology for revealing consumer preferences is *conjoint analysis*, where respondents' ranking of various combinations of attributes are used to determine preferences and trade-off dilemmas of the respondents. For example, Meuwissen and van der Lans (2005) apply customized conjoint analysis on Dutch pork consumers' trade-offs between food safety and other quality attributes, finding that food safety and animal welfare are the most important to consumers, together with taste and price.

Valuation of benefits through *market prices* relies on the differences between prices paid in markets for products with different safety attributes, using hedonic techniques (i.e. interpretation of price differences as premium for differences in risk) or by techniques based on people's averting behaviour. One challenge with the use of market behaviour to determine the value of changed food risk is whether people have full knowledge about the risks and their implications and whether people have the same skills in handling risks when preparing meals from potentially contaminated ingredients. In addition, consumers' behaviour on markets may depend on other elements than price or risk level, e.g. limited access or transaction costs related to switching food consumption towards safer product varieties, different levels of information and skills to avoid food hazards (Shogren et al., 2001). Furthermore, in some instances, consumers' degree of rationality and competence in decision making may be questioned. For example, studies show that people tend to underestimate risks of common causes of death, while they tend to overestimate risks of rare causes of death (Kenkel, 2001).

A fifth approach to measuring benefits of increased food safety is the *liability cost approach*, where benefits are measured in terms of the avoidable costs for parties in product liability cases. However, as pointed out by Caswell (1998) and Buzby and

Roberts (1997), data on actual costs of liability will often be hard to obtain because a significant share of cases are settled out-of-court.

The state-of-the-art concerning benefit evaluation regarding interventions to improve microbiological food safety is that the research discipline still faces some serious challenges. One issue is whether benefits related to reduced illness and consumers' willingness to pay for reduced food risk are additive – or alternatively if they should be considered as two ways of measuring the same benefit. Another issue is to what extent the benefits resulting from different elements of risk reduction (e.g. simultaneous changes in both salmonella, campylobacter, E.coli, etc.) are additive – from a health perspective as well as from a willingness-to-pay perspective. As raised by Hooker (2000), one challenge is the assessment of benefits (and costs) of pathogen reduction resulting from novel interventions.

Possibilities for benefits transfer in cost benefit studies

As noted by Kenkel (2001), different risks should be valued differently. Nevertheless, as valuation studies are often costly, there is a clear motivation to investigate the extent to which results from previous valuation studies can be utilized in cost-benefit assessments – within the field of food safety and from other fields of research. Krupnick (2001) investigates the possibilities for using benefits transfer in cost-benefit analyses of food safety. Two types of results can be used for benefits transfer: unit values (e.g. WTP for one “health unit”) and valuation functions (i.e. WTP for one “health unit” supplemented with information to adjust the values for the relevant policy context). There exists some literature on benefits transfer regarding air pollution, whereas the experience regarding food-borne illnesses is more scarce. Krupnick (2001) concludes that estimated WTP's from air pollution and labour market studies are not suitable with respect to food safety analyses because of differences in risk levels, the composition of groups exposed to risk, and the symptoms involved. On the other hand, transfer of COI benefit estimates may be more reliable.

Administrative costs

Administrative costs such as monitoring and regulatory enforcement, at the firm and the public agency level, can play a significant role in the overall assessment of costs and benefits – and can also be decisive for decisions made concerning interventions etc. Unnevehr and Jensen (1999) provide some general considerations concerning the adoption of HACCP with performance versus process standards, including the degree of flexibility allowed in different HACCP schemes. Crutchfield et al. (1997) estimate that costs of recordkeeping (recording, reviewing and storing data) account for more

than one third of the total costs of the US HACCP regulation on meat and poultry. Depending on the design of the HACCP implementation, the associated costs can be relatively high for small producers – an aspect that was dealt with in the final implementation of the US HACCP rule (Crutchfield et al., 1997). Henson et al. (1998) report from a survey study among EU dairy processing companies, finding that costs of record keeping is by far the most important operating costs associated with HACCP.

Costs and benefits associated with international trade

Countries' differential treatment of food safety concerns is a potential barrier to international trade, and thus to the exploitation of international comparative advantages. However, according to Roberts et al. (2001) there is evidence that the SPS Agreement within the WTO framework has improved transparency and the recognition of scientific approaches used for regulation in different countries. Unnevehr and Jensen (1999) consider the use of HACCP as a regulatory standard for international trade and point out that this will require a mutual recognition of HACCP implementation amongst WTO member countries – a recognition that is not yet established.

If a substantial share of domestic production is exported, not all benefits associated with food safety interventions will be accrued domestically. And vice versa, if a substantial share of domestic consumption is imported, there may still be health risks despite even total elimination of the risk in domestic production (e.g. Havelaar et al., 2005).

Discounting

As some food safety interventions may have implications over a long time horizon – on the benefit side for example because long-lasting or fatal disease cases may be avoided and on the cost side because some interventions require substantial investments – the issue of discounting may have an important role to play in cost benefit assessment of such interventions. It may be argued that for consumer-based programmes, relatively low discount rates, e.g. 1-3% (Roberts et al., 1996, Crutchfield et al., 1997), should be applied, because the opportunity yield would be the consumers' rate of time preference (which is often presumed to lie in that area). On the other hand, discount rate for industry-based programmes a corresponding to the alternative yield on investments should be used, e.g. 4-7%. Havelaar et al. (2005) use a 4 percent discount rate for assessing costs and benefits of controlling *Campylobacter* in the Netherlands.

Roberts et al. (1996) demonstrate that the valuation of benefits measured by reduced cost-of-illness and the value of statistical lives is quite sensitive to the discount rate. For example, in US HACCP programme, increasing the discount rate from 3 to 7 per cent reduces the calculated benefits over a twenty year time horizon by approximately one third. This is because a significant share of the reduced disease burden has long-term effects on costs. This is supported by findings from Crutchfield et al (1997, 1999). who evaluated the application of 3% and a 7% discount rates in their analysis. As most of the disease burden from *Campylobacter* is short-term, results with regard to this are not very sensitive to the discount rate (Mangen et al., 2005a)

4.3. Cost-benefit analyses on specific interventions and strategies

Since the mid-1990's, a number of cost-benefit studies regarding food safety interventions – and in particular HACCP programmes - have been conducted. Crutchfield et al. (1997, 1999) analyse the costs and benefits associated with the meat and poultry inspection procedures implied by the initially proposed US HACCP programme introduced in the late 1990's. Despite huge variation in the estimated benefits, they concluded that benefits in terms of reduced cost of illness would most likely exceed the costs of HACCP, but that costs would be relatively high for smaller processing firms. Roberts et al. (1996) provide a comparison between the initially proposed US HACCP programme and the finally implemented programme, showing that a modification of the test requirements in the final programme reduced the total costs of the programme, and in particular for small processing plants. Goodwin & Shiptsova (2002) have also evaluated the final US HACCP programme, taking into account market responses but using significantly lower health benefit estimates based on actually observed changes in pathogen risks within three years after the programme was implemented, and concluding that the programme has lead to a net welfare loss. Golan et al. (2000) used a SAM methodology to assess economy-wide effects of the final HACCP programme for meat and poultry, finding a net social welfare gain from the programme, based on the same health risk reduction assumptions as Crutchfield et al. (1997), but the net gain is narrowly connected to the reduction in premature deaths and loss of work days, whereas the reduction in insurance and medical expenses lead to a loss in economy-wide income.

Havelaar et al. (2005) examine the cost-utility implications of a number of specific interventions against *campylobacter* in the Netherlands chicken sector, at the farm, processing and consumer level. Their results indicate that reduction of faecal leakage from carcasses at the slaughterhouse level, possibly combined with chemical decon-

tamination, could be the most cost-effective way to reduce campylobacter. Also phage-therapy at the farm level may provide a relatively cost-effective intervention strategy, whereas interventions in terms of educating consumers are found to exhibit relatively low cost-effectiveness.

Andersen and Christensen (2004) have evaluated the Danish salmonella control programmes since the early 1990's by means of a computable dynamic general equilibrium modelling framework, taking into account second-round effects from reduced illness and investments in salmonella-reduction. They use a COI approach to estimate health benefits, but do not include the value of reduced mortality. They find that the control programmes have increased economic welfare but that it has taken approximately 10 years to obtain accumulated benefits that exceeded accumulated costs.

Romano et al. (2005) use an accounting approach, combined with in-depth interviews with quality managers in dairy and meat processing companies in Italy, UK and the Netherlands, to evaluate costs and benefits of compliance with EU HACCP regulation. They find that in most of the considered cases, compliance costs account for 1-2 per cent of total annual turnover. The results do not exhibit clear systematic patterns. Benefits are evaluated qualitatively based on the interviews and include higher awareness of production processes and better communication within the firms.

4.4. Perspectives on cost-benefit analyses and food safety

This chapter has dealt with some of the key topics in cost benefit analysis with regard to food safety policy interventions, discussing some of the principles and methods used for cost-benefit analyses as well as providing some examples of applied cost benefit analyses from the literature.

The use of cost benefit analyses may serve a number of purposes in the processes of policy planning, implementation and evaluation. In the policy planning stage, cost benefit analysis may serve as a tool for decision support for whether a food safety programme under consideration will be welfare-improving from an economic perspective – and for identifying if crucial elements for the programme are welfare-improving. If the introduction of a food safety programme has been decided, cost benefit analyses may serve as inputs to the specific implementation of the programme. The role of cost-benefit analysis in this process is illustrated by the above-mentioned US example, where cost benefit analyses of the initial meat and poultry HACCP programme revealed economic problems for smaller processing plants, and

this possibly lead to a programme revision that was beneficial for these smaller plants. Finally, cost benefit analysis can be used ex post for evaluation of food safety programmes, to decide whether the programmes should be maintained or modified.

One methodological aspect is crucial regarding cost benefit analyses: the valuation of non-marketed benefits and costs such as the value of reduced health risk. As the experience from the US HACCP programmes shows, especially the valuation of health benefits is highly important for the outcome of a cost benefit analysis. Furthermore, the available methodologies for such benefit assessment have several limitations, and are subject to considerable differences in the resulting benefit estimates as have also been discussed above. The most widely applied approach is the Cost of Illness method, which is fairly tractable but suffers from a lack of welfare economic foundation, whereas Willingness to Pay methods are in principle more theoretically well-founded but more difficult to measure empirically, and with more sparse literature. Consequently, there is a potential for developing methodologies for valuation of benefits from enhanced food safety. Krupnick (2001) suggests a number of areas for research:

- WTP applicable to children and household WTP
- WTP for combined improvements in mortality risk and morbidity
- Improving communication about small probabilities/conditional probabilities
- Altruism and WTP
- Qualitative risk attributes and WTP

In addition to the development of benefit valuation methods, there is also a need for a more systematic methodology to estimate administrative costs regarding food safety programmes, including costs of administration, monitoring, sanctions etc. Huusom (2005) has followed the research line of administrative and transaction costs, however mainly focusing on environmental regulation, but similar methodologies would probably be relevant regarding food safety strategies.

5. Conclusions and perspectives

A survey of the scientific literature was used to review the role of economics in food safety risk management and the current methodological state of the art concerning the evaluation of costs regarding microbiological food safety in a supply chain perspective. The section below summarizes and discusses some of the main findings from the review and draws some perspectives for regulation and research.

5.1. Summary and conclusions

Many complex issues are embedded in the consideration of food safety. Economics plays an important role in the public debate on food safety, and economic theory also helps explaining some of the key problems in the regulation of food safety, including incentive and information problems, uncertainty, etc. An economic issue of concern is how to best achieve the goal of safer food supplies, which embeds a concern for cost effectiveness. A dominating preventive approach to ensuring microbiological food safety in many countries is the Hazard Analysis of Critical Control Points (HACCP) approach, which identifies critical points in the production process by means of risk assessment, and if possible suggests actions to minimize risks in these points in the process. Among other methods is to treat contaminated foods by e.g. pasteurization/decontamination techniques.

In the selection of analytical approach to undertake cost assessments, it is important to be specific about the purpose of this assessment. One of the major aspects to address is whether the analysis should have a prescriptive or descriptive objective, i.e. whether the analysis should be used for recommending new initiatives or to evaluate already implemented methods. Another aspect is, whether or how the analysis should take into account societal benefits generated from considered food safety interventions, e.g. increased consumer trust, decreased prevalence of human disease, etc. From a policy perspective, such effects should be taken into account when designing policy interventions to reduce food safety risk, and a number of cost-benefit studies have addressed the issue, many of them based on one U.S. based cost-of-illness-founded benefit assessment study (Buzby et al., 1996). From a commercial perspective (e.g. marketing, image, CSR, etc.), the extent of such effects could also be relevant. A third aspect is whether the food safety issue should be considered from a firm, sector, supply chain, national or international perspective.

Within the field of cost analysis, much of the literature surveyed in this working paper basically represents 3 methodological approaches: accounting approach, economic-engineering approach and econometric approach. Each of these approaches has its own strengths and weaknesses.

Accounting approaches assume static behaviour and can be based on actual costs or budgets. Such approaches enable analyses at a relatively high level of detail – however depending on the level of detail in available data. On the other hand, the accounting approach does not take into account economic agents' possibilities for adjusting to the interventions and are hence most appropriate to address marginal changes and application of already known methods on new firms/plants. It may thus be more difficult to get meaningful results from this approach, if more radical strategies (strategies that may be expected to affect optimization behaviour in the food chain) are to be investigated. In such cases, the accounting approach may lead to a risk of overestimating the costs, because adjustment possibilities are ignored.

For situations where more radical strategies are considered, an *economic-engineering approach* may be more appropriate. This approach is often based on a normative optimization approach integrating technical aspects of reduction methods with economic aspects and taking into account the economic optimization of agents in the food chain, given certain food safety requirements and introduction of specific reduction methods. Some of the applications take into account the stochastic nature of food safety hazards. One weakness of economic-engineering approach is the normative character of the approach, which states high requirements to the explicit specification of all details of the optimization behaviour, including the objective function as well as all restrictions, if the analyses are to be realistic. Lack of information on some of these elements or restrictions may imply a risk of overestimating the adjustment possibilities and hence underestimating the costs induced by new interventions.

In contrast to economic-engineering approaches, *econometric approaches* build on theoretically derived equations, which correspond with existing empirical data and hence can be estimated using statistical/econometric methods. Often, this implies that the approach does not require as detailed specification requirements for obtaining relevant results as are needed in order to conduct an engineering approach, because the existing (observable as well as unobservable) restrictions are embedded in the empirical data. A priori, it is not straightforward whether the approach is likely to over- or underestimates the costs of food safety interventions. On the other hand, as the econometric approach poses strong requirements for a sufficient number of obser-

variations to conduct statistical analysis, the approach is most suitable for analysing costs and effects of already established reduction methods.

Within these generic approaches – and in particular within the range of economic-engineering analyses – the surveyed literature represents considerable diversity in the level of detail and specification of processes, cost items, etc. Some studies have assumed deterministic conditions, whereas others have been based on risk assessment studies and hence specify specific stochastic processes for various food safety variables.

At a more aggregate policy formulation level, it will often be relevant to consider the costs of a food safety policy strategy in light of the societal benefits to be obtained by the strategy, within a cost-benefit analytical framework. In such cases, the economic valuation of societal benefits – mainly in terms of reduced costs of illness and improved consumer utility - becomes a key element. Most of the existing studies in this field are based on the so called cost-of-illness methodology, where societal gains from improved food safety are valued in terms of the reduction in lost working days due to reduced morbidity and mortality and possibly reduced health care costs. A few studies estimate the value of improved food safety through consumers' increased utility.

As mentioned, the choice of analytical approach depends on the analytical purpose. Furthermore, the choice of approach will depend on the scope of analysis, e.g. process, firm, sector, chain, national or international level. For example, a firm or supply-chain level cost analysis may ignore effects that are irrelevant to the firms considered (externalities or market effects), whereas a society-level analysis may benefit from including such effects, although the quantification and valuation of some of such these effects may be highly uncertain and require advanced model tools, etc.

As discussed in the previous chapters, the issue of food safety and costs associated with food safety has been a topic in the scientific literature during the last decade. The scope of the analyses has mainly been to assess the costs to the relevant production sectors due to selected strategies to reduce the risk of contamination. Most of the studies reviewed in this paper have focused on either evaluation of existing action plans or implementation of specific intervention strategies to reduce food safety risk. On the other hand, rather few studies have been found which address the issue of cost-effective design of intervention strategies, e.g. what would be the cost-effective level and mix of interventions etc.?

5.2. Perspectives for research in food safety costs

Cost analysis related to microbiological food safety is an example of a multidisciplinary field of research, where insights from natural sciences are combined with methods from economics and other social sciences. Measurements of the effects of food safety interventions are often based on methods and data from natural sciences, whereas the measurement of costs are based on economic methods.

Most of the studies considered in this review provide results on the costs of various strategies to improve microbiological food safety – many of them undertaken in the United States. But can results from such studies be transferred to e.g. another country, or should such results be expected to be highly context-dependent? It appears that although the underlying microbiological processes may be identical across countries, a number of the economic elements of the analysis seem to be highly dependent on the specific contexts. This is the case with regard to e.g. prices and wages, and possibly also elements like health care costs, liability costs etc. However, there is a need for further investigation concerning the international transferability of results from food safety cost analyses.

The vast majority of the surveyed literature represents studies of cost at the firm or sector level, or cost-benefit relationships at the sector or society level. On the other hand, the occurrence of studies addressing costs and cost-effectiveness of food safety motivated interventions in a supply chain setting is rather scarce. Such chain perspective analyses might however be useful for uncovering incentive structures and interactions between different stages of the food supply chains (see e.g. Baker, 2007).

One issue for further research within the supply chain perspective is the exchange of information between various stages of the chain – and participants' economic incentives in this respect. Do some of the participants have economic incentives to withhold food safety information from the other participants? And can these economic incentives be changed in order to enhance the level of information? Another aspect related to the issue of asymmetric information. That is to what extent do regulator authorities' attain level of information is optimal to ensure an appropriate intervention policy and ensure the provision of economic incentives for how food supply participants' could to improve their supply of information to the regulating authorities.

Food safety intervention strategies are associated with transaction costs, including costs of administration and monitoring. In the studies surveyed, however, this aspect

has only gained minor emphasis – from a data as well as from a methodological perspective. For some types of intervention, especially these types of costs may be central for their possible implementation.

In chapter 4 of this paper, some of the applied methodologies for benefit valuation have been referred, with two approaches dominating the literature – cost-of-illness, which is based on cost savings for individuals and society, and willingness-to-pay, which is based on individuals' utility derived from consumption of safe or less safe foods. However, there seems to be a lack of suitable and holistic concept of how benefits can be estimated – possibly based on integrating the two applied approaches. To this end, the valuation of societal benefits has only to an indirect extent taken into account the distinction between the consumer perspective and the citizen perspective to the benefits of food safety. The citizen perspective refers to non-use values of microbiological food safety.

Hence, although a considerable list of literature on the economic perspectives to microbiological food safety exists, as demonstrated in this working paper, there still remain a number of substantial issues, where further research is needed to improve the possibilities for proper analysis of the economic consequences of various intervention strategies to enhance the level of food safety.

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